

Part 5:

Conflict and Concerns

POTENTIAL EFFECTS OF WILD RICE (*ZIZANIA PALUSTRIS* L.) INTRODUCTIONS ON LAKE ECOSYSTEMS: A LITERATURE REVIEW

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ABSTRACT

Promotion of wild rice as a commercial product has lead to a considerable increase in its distribution throughout northern Manitoba, Saskatchewan, and Alberta. Wild rice continues to be introduced into Manitoba lakes without science based consideration of its potential effects on lake ecosystems. Disturbing the macrophyte community composition or abundance in lakes can cause widespread but often subtle ecosystem changes. Dense stands of wild rice may alter the chemical, thermal, and nutrient dynamics in lakes. The decomposition and accumulation of wild rice straw may alter lake sediments and come to overlie areas in which fish spawn. The introduction of wild rice into a lake may lead to significant changes in the community composition and density of its macrophytes. This may cause changes in the abundance and community composition of the invertebrate and fish communities within the lake. Dense wild rice stands may displace recreational anglers by reducing access to some areas, which could result in severe impacts on the local economy. It is virtually impossible to remove wild rice from a lake after it has been introduced. Proper scientific attention is needed to assess the effects that wild rice has on lake aquatic ecosystems before further introductions take place. The decision to introduce wild rice into lakes should reflect not only the potential benefits to local economies, but the potential detriment to lake ecosystems as well.

INTRODUCTION

Northern wild rice, *Zizania palustris* L., is an emergent macrophyte native to southeastern Manitoba and the Great Lakes regions of the United States and Canada (Dore 1969). The promotion of

wild rice as a commercial product has extended the distribution of this annual aquatic grass to include lakes in more northern areas of Manitoba, Saskatchewan, and Alberta. (See Figure 1.) The introduction of wild rice into the west-central portion of Manitoba began in the early 1980s, and between 1988 and 1998, the distribution of wild rice in Manitoba increased considerably. (See Figure 1.) Wild rice continues to be introduced into Manitoba lakes without science-based considerations of potential effects on lake ecosystems.

Aquatic macrophytes are important components of lake ecosystems. Macrophytes function as a resource base for fish and a refuge from predation, affecting both the competitive and predatory interactions among fish species and size classes within species (Persson and Crowder 1998). Vegetated areas in lakes affect macroinvertebrate, zooplankton, and phytoplankton production. This can influence the species composition, growth, and abundance of fish (Diehl and Kornijów 1998).

With this review, we attempt to identify the potential effects that the introduction of wild rice into a lake may have on its ecosystem, fishes, and fish habitat and suggest areas in which future research may be warranted.

PHYSICAL CHANGES

Water chemistry in an aquatic macrophyte bed varies seasonally as macrophytes grow, die, and decompose (Morin and Kimball 1983; Carter et al. 1991). Under the appropriate conditions, wild rice can be a vigorous competitor with native aquatic plants and form dense monotypic stands (Lee 1986). The density of a macrophyte bed can affect vertical thermal and oxygen concentration gradients within

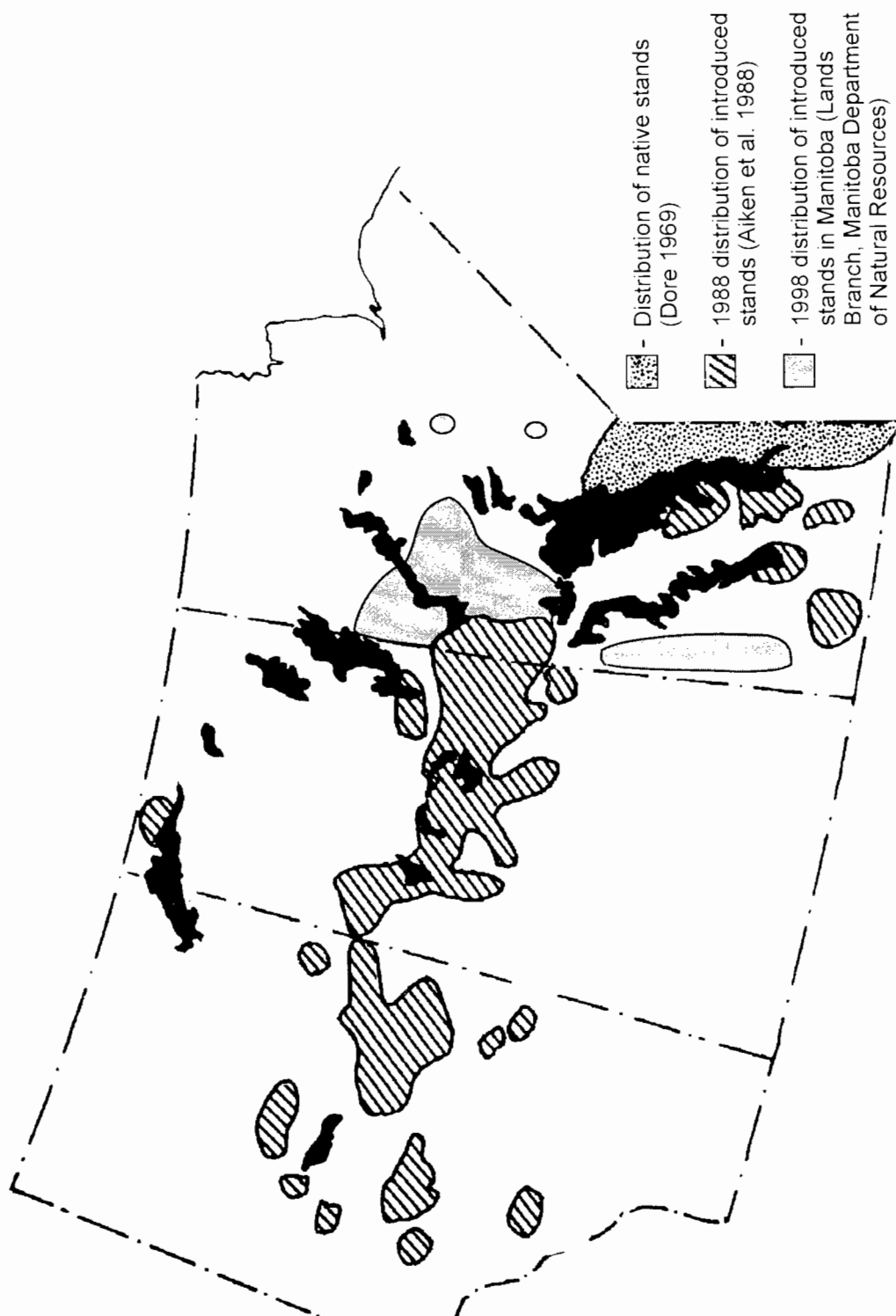


Figure 1. Distribution of native and introduced stands of northern wild rice (*Zizania palustris* L.) in central Canada (after Aiken et al. 1988).

them (Morin and Kimball 1983; Carpenter and Lodge 1986; Carter et al. 1991). Wind induced water circulation, which eradicates vertical thermal and chemical gradients, is impeded by macrophyte beds. The decomposition of plant material uses large amounts of oxygen and leads to decreased oxygen concentrations in poorly circulating waters (Carpenter and Lodge 1986).

Straw residues may be an important environmental concern associated with the introduction of wild rice into a lake. At the end of a growing season, almost all the straw from a wild rice stand remains in a lake and often accumulates on the bottom of dense rice stands (Lee 1986; Archibold 1990). This straw may take up to three years to completely decompose (Sain 1984). The accumulation of rice straw may cause the smothering of rice seeds, other macrophytes, or fish spawning grounds. Straw decay is a valuable source of nutrients for subsequent rice crops, other plant growth, and for the support of more complex macroinvertebrate communities. Keenan and Lee (1986) found that in dense stands of wild rice, the amount of nitrogen, phosphorus, and potassium available for macrophyte growth and reproduction is depleted significantly after only a few years. In addition, much of the straw is mobile and is carried by wind, ice, and currents to be deposited on shore or in other open areas (Aiken et al. 1988). The decomposition of vegetation can redistribute lake sediments (Engel 1990), and the sediment derived from decomposed wild rice straw may come to overlie, and thereby destroy, productive fish spawning sites.

INVERTEBRATES

Epiphytic communities are important food sources for macroinvertebrate grazer communities. An increase in macrophyte abundance increases the amount of habitat available for colonization by epiphytic organisms (Carpenter and Lodge 1986), which in turn augments the total production of grazer macro-invertebrates (Rabe and Gibson 1984; Wiley et al. 1984). Benthic invertebrates often are much more abundant in the sediments of vegetated areas than in sediments of open areas (Wiley et al.

1984; Engel 1988; Diehl and Kornijów 1998). There is a similar positive relationship between zooplankton and macrophyte densities (Rabe and Gibson 1984; Wiley et al. 1984; Cyr and Downing 1988; Jeppesen et al. 1998). Macroinvertebrates are attracted to vegetated areas because they provide a greater surface area and diversity of substrates to use as a food source and shelter from predators (Rabe and Gibson 1984; Wiley et al. 1984; Engel 1990; Diehl and Kornijów 1998).

Under the appropriate conditions, wild rice can be a vigorous competitor with native aquatic plants and form dense monotypic stands (Lee 1986). Since invertebrates are a major food source for at least some stage in the life history of most fishes, the production of fish in lakes often is correlated with macroinvertebrate production (Hanson and Leggett 1982). The introduction of an exotic plant species into a lake, thereby altering the plant community, may cause changes in the abundance and community composition of the macroinvertebrate community within the lake. This could have unknown consequences for fish populations (Hanson 1990).

FISH

Dense macrophyte coverage in lakes has been shown to negatively affect fish growth and production (Bettoli et al. 1992; Cross et al. 1992; Olsen et al. 1998). Macrophyte removal is an important management tool for improving fish growth rates and size structures in lakes with high amounts of vegetative cover (Olsen et al. 1998).

Large piscivores forage poorly in dense vegetation, and their growth rates decrease with increasing macrophyte densities (Savino and Stein 1982; Engel 1985; Ryer 1988; Gotceitas and Colgan 1989). Smaller fish seeking refuge in macrophytes may experience accelerated growth in a resource (invertebrate) rich environment. However, if the densities of small fish in the vegetated areas are high enough, slower growth rates may result. It has been shown that increasing competition among fish seeking refuge can lead to an overexploitation of prey resources (Mittelback 1988; Persson 1993).

Different species of predators are affected differently by vegetation. For example, Eklöv (1992) found northern pike have higher foraging rates in macrophytes than do yellow perch, but the reverse occurs in open areas. Increased abundance of macrophytes could cause a competitive advantage for some fish species and lead to significant changes in fish community structure (Bettoli et al. 1993).

OTHER POTENTIAL IMPACTS

Wild rice introductions may have other impacts on lake ecosystems. Dense rice stands would reduce the wind and wave action that shapes the shorelines and stirs the sediments of lakes (Engel 1990). More difficult to assess are the aesthetic changes to lakes, which may drive recreational lake users away because of choked waterways and beached straw (Colle et al. 1987; Olsen et al. 1998). High densities of macrophyte cover drive away recreational anglers by reducing access to some areas, resulting in severe impacts on the local economy (Colle et al. 1987; Slipke et al. 1998).

Wild rice may be virtually impossible to remove once introduced into a lake. Oelke et al. (1982) reported that wild rice seeds can remain dormant in sediments for up to six years. Even if removal was possible, the effects of the sudden loss of wild rice beds could be detrimental. Engel and Nichols (1994) reported a case where the destruction of wild rice beds in a Wisconsin lake allowed winds to suspend soft flocculent sediments. The increased water turbidity led to lower abundance and diversity of its macrophyte community, a condition that lasted for more than a decade.

FUTURE RESEARCH

Disturbing the macrophyte community composition or abundance in lakes can cause widespread but often subtle ecosystem changes (Hanson 1990; Engel 1990; Carpenter and Lodge 1986). Any predictions of the long-term effects of changing the macrophyte composition and abundance on fish communities and fish habitat can be merely speculative. The points raised previously suggest

that proper scientific attention examining the effects that the introduction of wild rice has on aquatic ecosystems, particularly on the littoral zones of lakes, is merited. These effects can be determined only through multi-year, experimental, and comparative studies at the whole-lake level. What is needed, before and after wild rice introductions, are estimates of seasonal patterns of:

- the extent, density, and species composition of macrophyte beds;
- the abundance, size structures, growth rates, species composition, prey items, and habitat usage of fish populations;
- the abundance, species composition, and production of macroinvertebrates in different types of macrophytes and sediment;
- the production of phytoplankton and zooplankton;
- water temperature, quality, and clarity; and
- sedimentation rates in fish spawning areas.

Wild rice introductions should have been, and in the future should be, approached as one would any other introduction of an exotic species. Detailed studies are needed to assess the potential biological and social impacts that the introduction of wild rice might have on aquatic ecosystems. These studies should include the possible displacement of sport and commercial fisheries, recreational use of lakes, changes in water quality, potential destruction of fish habitat and spawning beds, changes in primary production, and changes in fish communities. The decision to introduce wild rice into lakes should reflect not only the potential benefits to local economies, but the potential detriment to lake ecosystems as well.

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TESTING THE EFFECTS OF MOTORBOATS ON WILD RICE (*ZIZANIA PALUSTRIS* VAR. *INTERIOR*)

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ABSTRACT

The lakes of northern Wisconsin are popular vacation havens, and motorboat traffic, which is dense during the summer months, can impact aquatic macrophytes in a variety of ways. Motors and boat hulls cut and uproot growing plants; wave action creates turbid waters and impedes submerged growth while the suspended particles scour leaf and root tissue. Furthermore, boaters introduce invasive plants from other waters. Studies of motorboats and aquatic macrophytes often cite siltation and seed burial as a cause for stunted growth and decreased density. Siltation and aeration were the primary variables in a controlled experiment done at the University of Wisconsin Arboretum. The experiment tested germination success and growth rates of wild rice. It was hypothesized that wild rice germination is impeded when seeds are buried too deeply in silt because of a lack of available oxygen. Wild rice germination was significantly reduced when seeds were buried 4 cm deep; however, aeration had only a moderate impact. At Allequash Lake, Wisconsin, some wild rice beds are exposed to frequent boat traffic while others are off limits to motorboats. Wild rice plants exposed to boat traffic were less dense, shorter, often had bent or broken stems, and nearly always had a high proportion of their total mass devoted to root tissue. Field data combined with previous controlled experiments suggest the poor health of the wild rice and that the disproportionate root mass was due to physical tissue damage.

INTRODUCTION

Wild rice (*Zizania palustris* and *Zizania aquatica*) grows in shallow, slow moving water where the bottom is a flocculent, organic muck. Once abundant throughout Canada and the Great Lakes region, wild rice is steadily declining due to human

and natural disturbances. Dams, diversion, exotic species, and over-harvesting are just a few of the causes linked to the wild rice decline (Clay and Oelke 1987; David 1997; Vennum 1988).

There are two main varieties found in Wisconsin: a riverine variety known as *Zizania palustris* var. *palustris* and a lake variety known as *Zizania palustris* var. *interior*. The riverine variety grows in slow moving water and is usually taller than the lake variety. Wild rice produces a mineral rich grain that is a delicacy for people and birds alike. In addition to food, wild rice beds provide cover for nesting wading birds and act as an underwater safe haven for fingerlings and other small fish.

The Great Lakes region is also home to several Ojibwe (Chippewa or Anishinabe) bands whose ancient ties to wild rice have bound them to the land for thousands of years. Wild rice, otherwise known as *manomin* (pronounced "mah-no-min"), is a cultural thread that winds through Ojibwe language, legend, and tradition. Northern Wisconsin, checkered with six Ojibwe reservations, is also a popular vacation destination for thousands of tourists. Wisconsin's northwoods attract campers, hikers, boaters, wildlife enthusiasts, and people who fish. Native and non-native people are concerned that motorboat traffic is damaging the cultural and ecological integrity of wild rice beds in northern Wisconsin (Vennum 1988; Schlender 1998).

Across the world, researchers are discovering that motorboat traffic affects a wide spectrum of aquatic conditions. Motorboats moving at moderate to high speeds "churn up" the bottom sediment, which can cloud the water for several hours, and the movement and distribution of silt within boat wakes has the potential to dramatically alter the characteristics of a water body (Johnstone et al. 1985; Yousef et al. 1980; Chambers 1987).

In shallow waters, boat wakes severely erode banks as well as the substrate supporting macrophytic communities along the shoreline. This "underwater erosion" can eventually cause whole beds to break off and float away (Asplund 1997). Shoreline and underwater erosion can potentially alter the substrate to one that no longer supports wild rice.

Wild rice, like other aquatic annuals, is exceptionally vulnerable to the invasion of aggressive, perennial species (Mitsch and Gosseling 1993). Water lily, purple loosestrife, bur reed, and bulrush are common wild rice competitors. Boat hulls, fishing nets, and motors readily transport aquatic plants and plant fragments from one lake to another. Increased boat activity in northern Wisconsin increases the introduction opportunity of aggressive species into wild rice waters.

OBJECTIVES AND HYPOTHESES

My first objective was to observe wild rice health (plant density, stem height, and biomass) in high impact and low impact areas. I hoped to monitor beds directly in the line of frequent, motorized boat traffic and isolated beds (as a control). As these would be my initial observations, any patterns I observed could only reflect a correlation and not a causal effect due to boat traffic.

In addition, after reviewing the literature I strongly suspected that the critical element linking motorboat traffic and its impact on macrophytic communities is due to an increase in sedimentation caused by erosion and/or boat wash. Thus, I developed and tested four hypotheses in a controlled setting:

1. Wild rice germination is negatively affected when seeds are buried in silt > 3 cm.
- 1a. The negative correlation is weakened as dissolved oxygen levels increase in water.
2. A negative correlation exists between wild rice stem growth and sedimentation at the plant base.
- 2a. The negative correlation is weakened as dissolved oxygen levels increase in water.

DESCRIPTION OF SITE

Allequash Lake is shaped like a dumbbell with a forty-pound weight on one side and a twenty-pound weight on the other. (See Figure 1.) Nestled in the American Legion-Northern Highland State Forest, Allequash Lake is completely void of lakeshore development but is a popular attraction to recreationists and wilderness campers. Gasoline-powered motors are only permitted on the large portion of the lake (the large dumbbell). Electric-powered motors are the only type of motor allowed in the small portion of the lake (the small dumbbell). Both sides contain wild rice beds (*Zizania palustris* var. *interior*), including the channel connecting the two areas. There is one boat landing in the channel.

In July, 1998, I made several observations. The wild rice exposed to motorized traffic appeared sickly when compared to the rice in the electric-motors-only areas. In general, the stems were thin and the plants tended to lean away from the boat channel. Broken and uprooted plants floated among the spindly stems growing at the rice-water interface. Perfect, rectangular holes the size of a small fishing boat were carved out of the wild rice beds at numerous places. Where the rice had been was a patchwork of open water and water lilies.

In 1998, I visited Allequash Lake in mid- and late summer as well as early fall after the harvest. During each visit, I counted the number of boaters in the motorized and electric-motors-only areas.

I was at Allequash Lake only on weekends, but I never saw less than 30 boats per day in the motorized portion—many traveling at speeds great enough to produce large wakes. In the electric-motors-only side, I never saw more than 10 boats in a day and the boat speeds were much slower.

Field Observations

I monitored five wild rice sites at Allequash Lake during the summer of 1998. I selected two wild rice beds in the motorized area (sites 1 and 2) in addition to the large bed in the electric-motors-only area (site

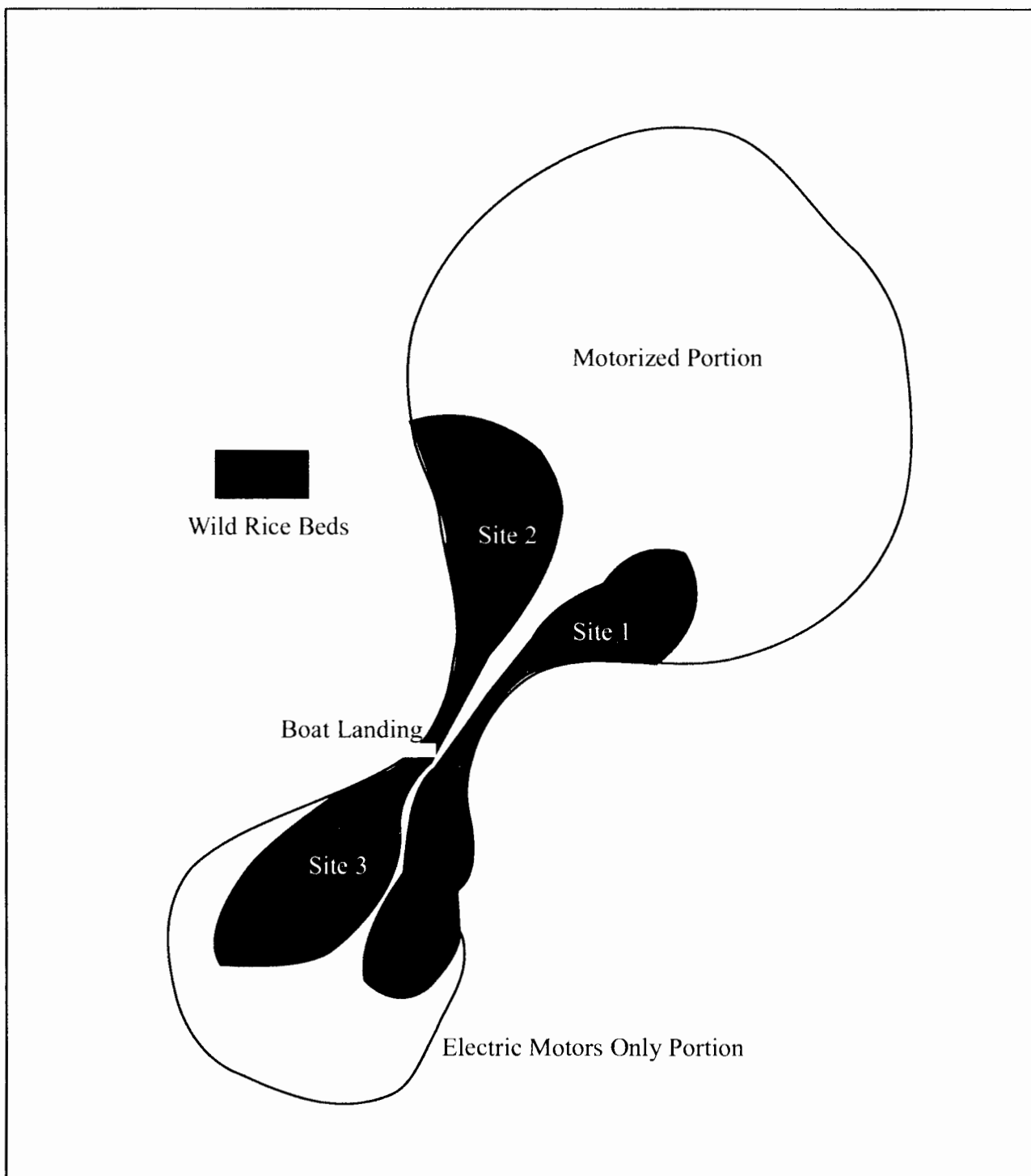


Figure 1. Allequash Lake and Sites

“3 no boat”). In the motorized portion, I monitored each site in two different places: the water-rice interface (sites “1 interface” and “2 interface”) and 5 m into the bed (sites “1 bed” and “2 bed”).

In August 1998, I measured stem density using a large hoop of known diameter attached to a 1-m rope that I tossed five times into each site. I counted the number of stems inside the hoop after each toss but was unable to determine which stems were tillers and which were separate plants. I also measured the stem heights and water depths (five measurements at each site) using a meter stick and notched string.

Later in the fall, after the wild rice harvest, I carefully uprooted 12 plants from each site and analyzed them for further differences. In the field, I measured stem and nodal root length and counted tillers and prop roots of each plant. The plants from site 3 (“no boat”) were noticeably larger and heavier than those in sites 1 and 2. The plants from the motorized boat side were often broken, bent, leafless, or seedless.

When I returned to the lab, I dried the samples in a Blue M Electric Stable Therm oven at 50°C for 36 hours and divided each plant into three parts: shoot and leaves, prop roots, and aerial roots. I crushed and combined the respective plant segments from each site and, at room temperature, measured the combined mass using a Sortorius 1212MP scale.

Field Results

Average water depth ranged from 70 cm to 1 m with the deepest recordings taken at site 3. Stem density was seven times greater in the electric-motors-only bed (see Figure 2 and Table 1) compared to the interface of sites 1 and 2, and the plants at site 3 stood 50% taller than in the motorized areas (see Figure 3 and Tables 2 and 3).

Table 1. Stem density (plants per square meter), n = 5; p-values represent differences between variable and control sites.

	1 Interface	2 Interface	3 No Boat
mean	10	10.5	70
st. error	4.320494	8.386497	0
p-value	0.000102	0.000758	

The above-ground portions of the plants removed from site 3 were massive in comparison to those taken at sites 1 and 2. There was an insignificant difference, however, between the plants’ root mass at every site. (See Figures 4 and 5 and Table 4.) Because the samples were lumped together before weighing, I was unable to perform any statistical analyses for plant mass.

MATERIALS AND METHODS

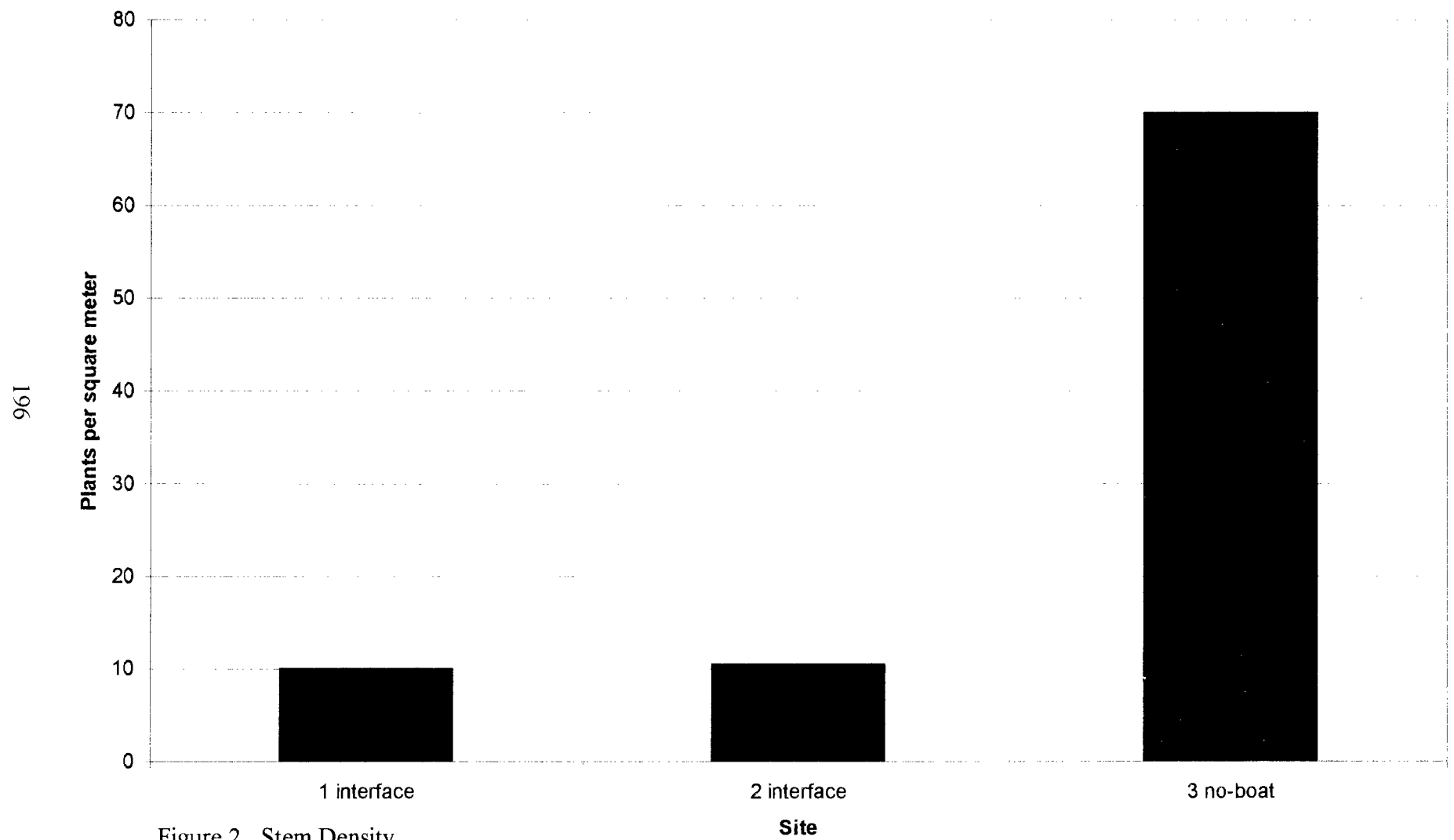
Controlled Experiments

Hypothesis 1 (restated): Wild rice germination is negatively affected when seeds are buried in silt > 3cm.

To test this hypothesis, I buried wild rice seeds 2, 3, or 4 cm deep in a highly organic substrate and placed them in water hosting varying levels of dissolved oxygen. I sowed six wild rice seeds in pots resting in 5-gallon buckets full of fresh water. I randomly assigned seed depths to each pot and maintained the water level at 25 cm above the surface of the substrate in the pots. To change the water, every two days I placed a hose at the bottom of the buckets and ran the water the length of time it would take to fill an empty bucket (approximately 1.5 minutes).

Hypothesis 1a (restated): The negative correlation is weakened as dissolved oxygen levels increase in the water.

To vary the dissolved oxygen in the water, I aerated the buckets at three levels using large fish aquarium pumps, air tubes, and air stones. A third of the buckets received no aeration, a third received 15 to



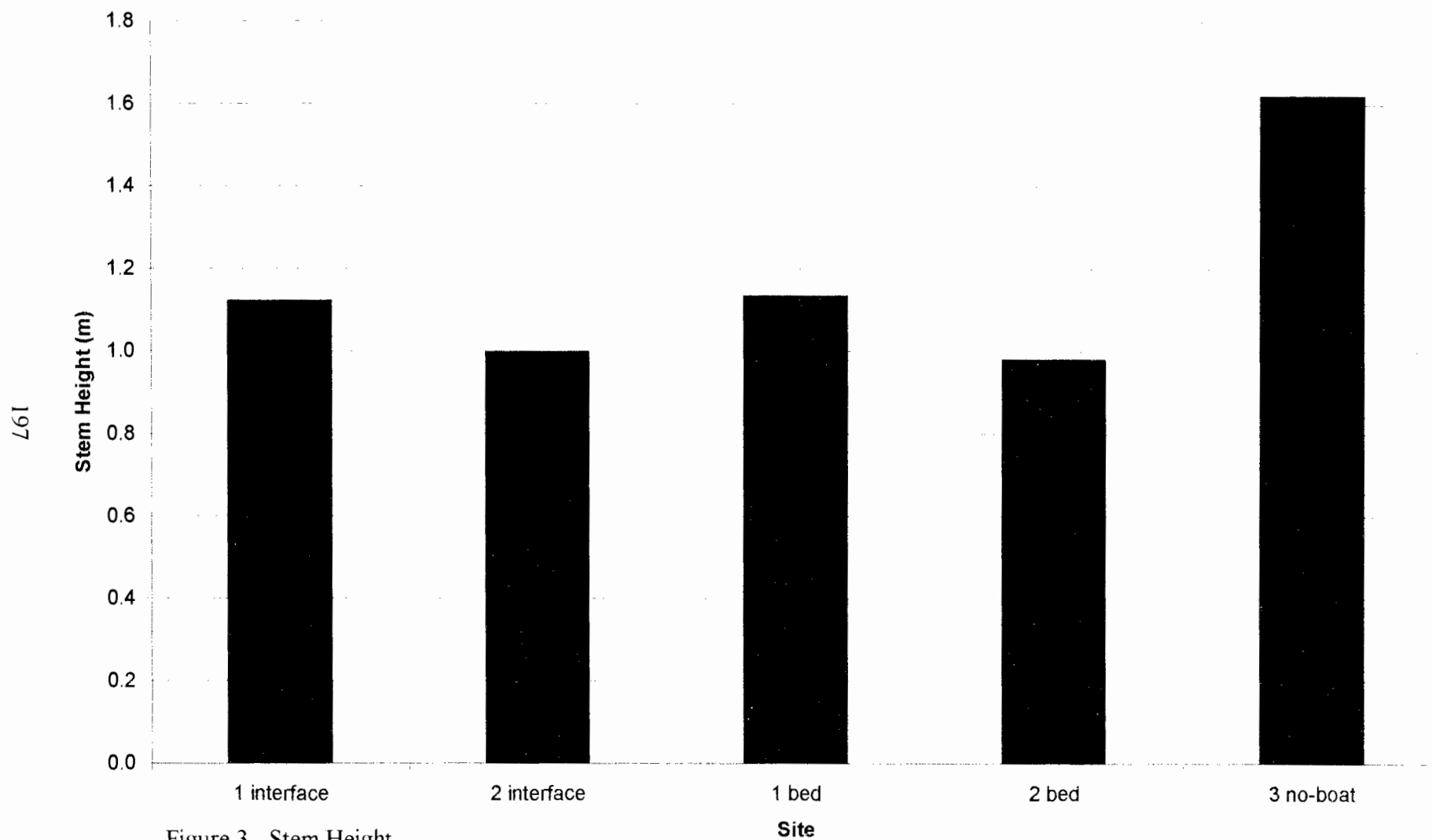
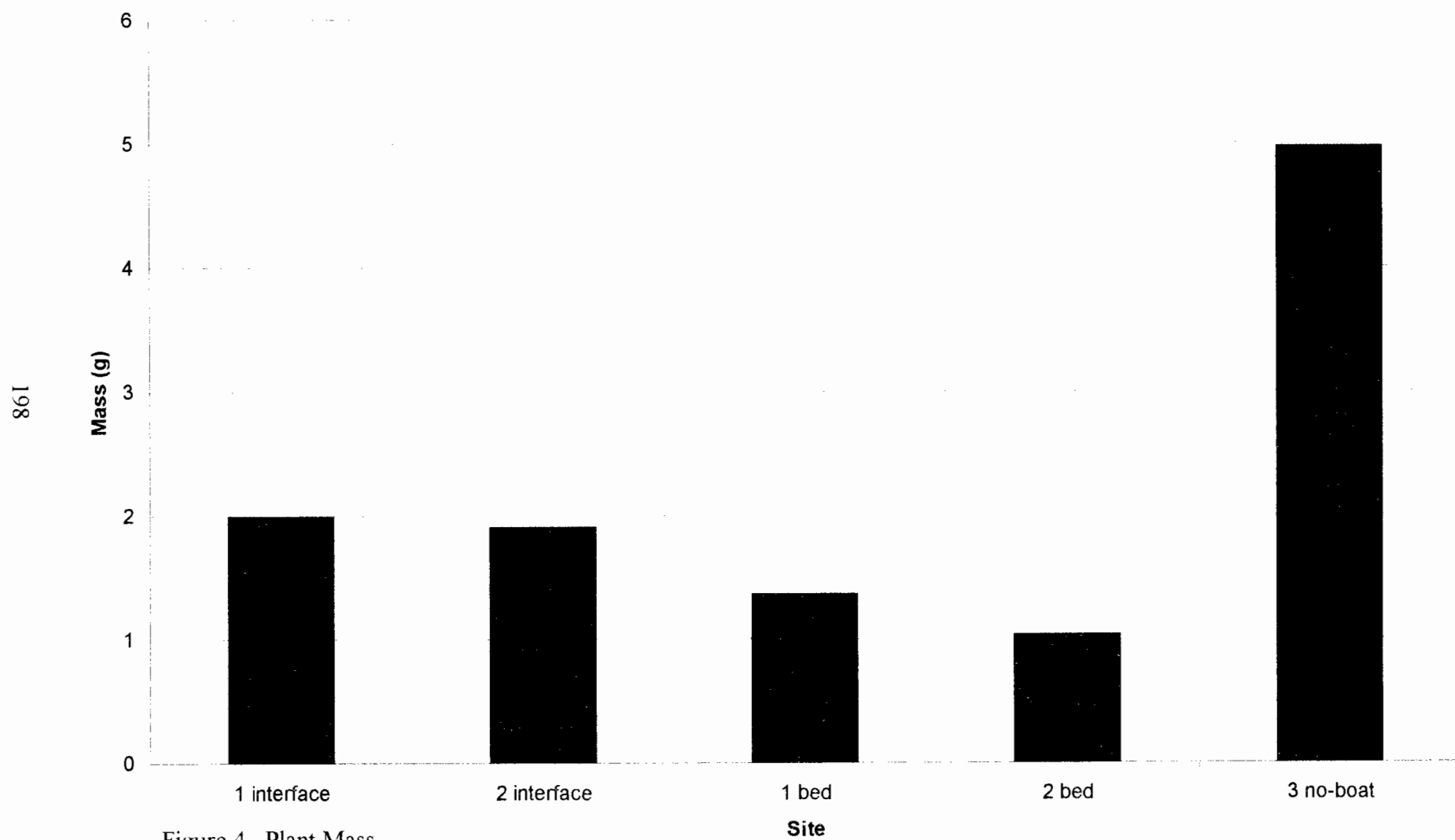


Figure 3. Stem Height



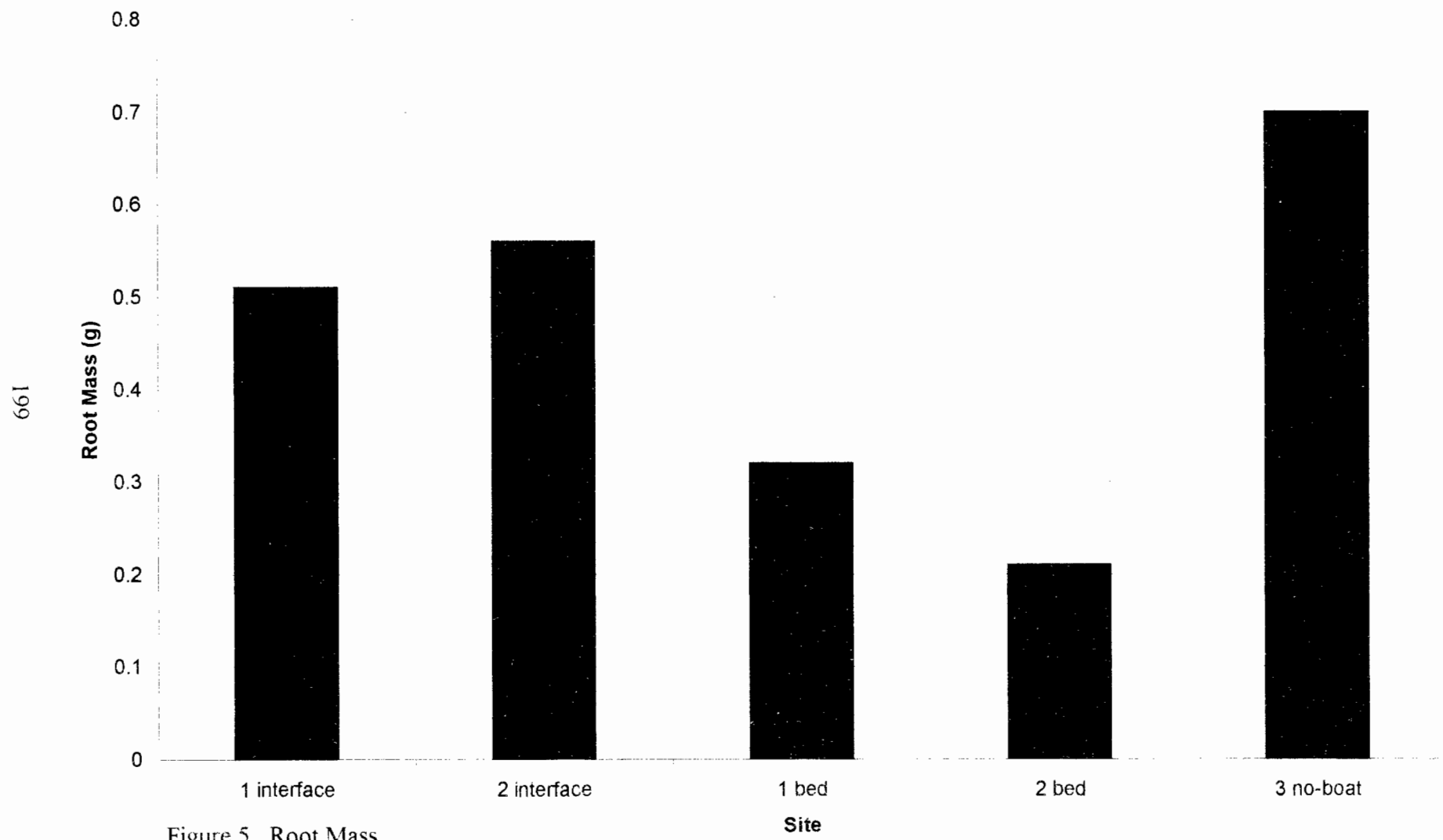


Table 2. Stem height (cm), n = 12.

	1 Interface	2 Interface	1 Bed	2 Bed	3 No Boat
mean	1.122	0.997	1.133	0.980	1.620
st. error	0.314	0.099	0.096	0.098	0.084
p-value	0.000157	1.04E-11	4.21E-09	1.65E-12	

Table 3. Differences of least squares means for stem height.

	1 Interface	1 Bed	2 Interface	2 Bed	3 No Boat
1 Interface		0.775065	0.298051	0.15967736	0.000157
1 Bed			0.020148	0.008803891	4.21E-09
2 Interface				0.768913439	1.04E-11
2 Bed					1.65E-12

Table 4. Mean plant mass, n = 12.

	3 No Boat	2 Bed	2 Interface	1 Bed	1 Interface
Avg. below ground mass (g)	0.65	0.21	0.56	0.32	0.51
Avg. above ground mass (g)	4.32	0.83	1.35	1.04	1.48

25 ml/s of air, and a third received 26 to 35 ml/s of air. The buckets were also randomly assigned aeration levels. The aquarium air stones rested 20 cm below the surface of the water, and I controlled the air pressure with valves connecting the main air lines to the air stones.

Hypothesis 2 (restated): A negative correlation exists between wild rice stem growth and sedimentation at the plant base.

To test the second hypothesis, I placed a second pot containing several seeds sown 0.5 cm deep into each bucket. Of these seeds, I allowed three wild rice plants to grow to the floating leaf stage before testing. If more than three seeds germinated, I cut the excess plants immediately.

Similar to the germination experiment, I maintained the water level at 25 cm above the surface of the substrate in the pots. I changed the water every two days by placing a hose at the bottom of the buckets and running the water the same length of time it would take to fill an empty bucket (approximately 1.5 minutes).

Hypothesis 2a (restated): The negative correlation is weakened as dissolved oxygen levels increase in the water.

I aerated the buckets in exactly the same manner as in the germination test. Each week, I made an "artificial" sediment with 20% sand and 80% garden-store peat in quantities roughly equivalent to 1, 2, and 3 cm³ of silt per plant. I poured the silt directly on the base of the growing plants with a plastic pipe that acted as a funnel. I measured the stem length (cm) of each plant (including tillers) every two weeks for six weeks.

The experiment consisted of 45 randomly assigned buckets set in three rows of fifteen: three siltation levels/germination depths crossed with three aeration rates and five replicates. (See Figure 6.) I insulated the entire experiment with wood chips piled nearly to the top of each bucket. In addition to measuring germination success and stem height, I also monitored oxidation-reduction potential (ORP), clarity, pH, and temperature.

The generated data sets are repeated measures with two treatments and time. The data was analyzed

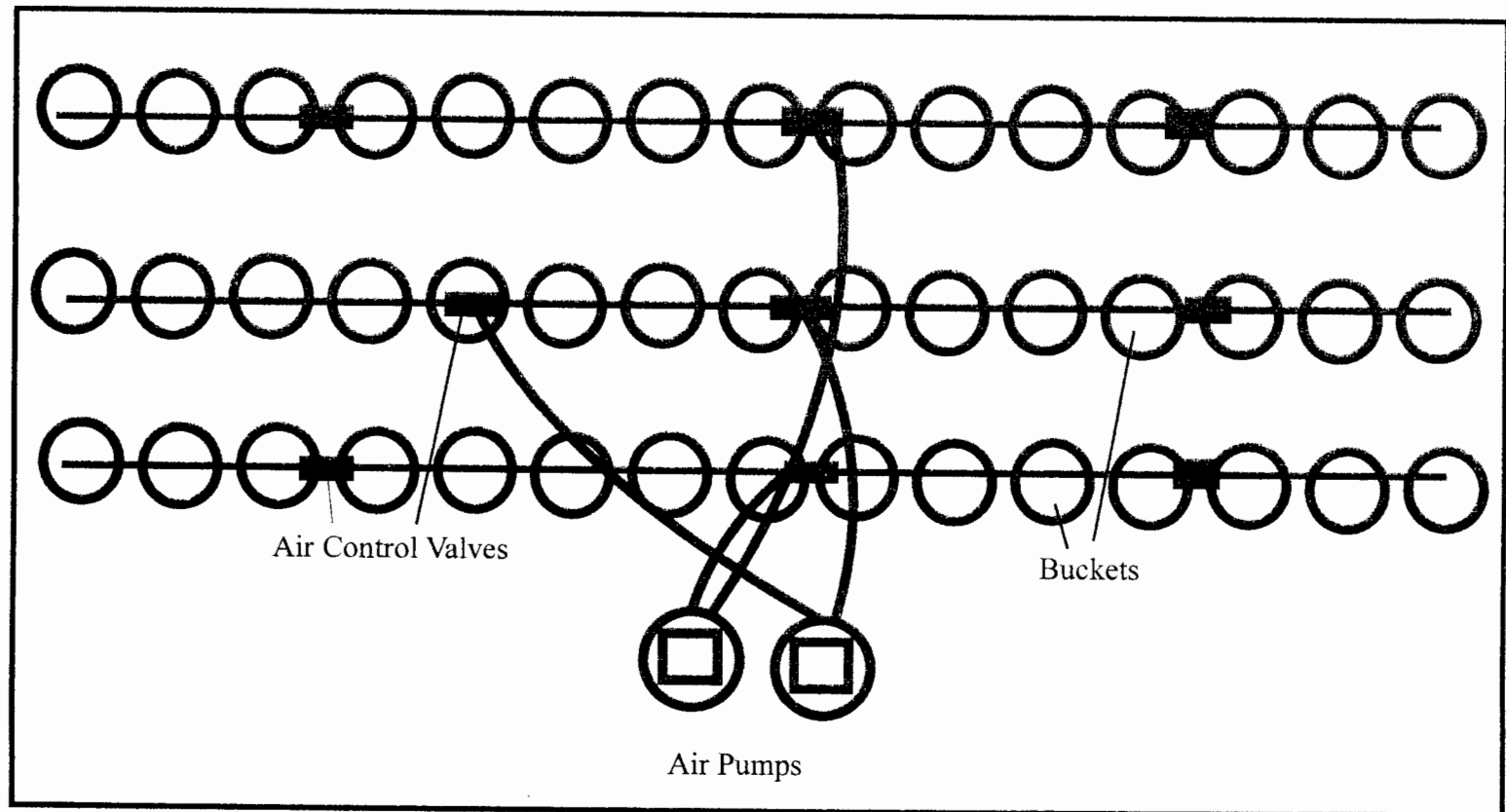


Figure 6. Experiment Design

using the Mixed Model Analysis of Data from Basic Repeated Measures. The experiment was designed so the data sets are randomized, and I assumed variation is from a normal distribution.

RESULTS

Hypothesis 1

There was no significant relationship between wild rice germination and aeration. However, seed burial positively and negatively affected germination. (See Figure 7 and Table 5.) Seeds sown 3 cm deep revealed a significantly greater germination rate compared to seeds sown 2 or 4 cm deep.

Standard Deviations

2 cm	3 cm	4 cm
0.941123948	1.387015	1.125463

Table 5. Germination Analysis of Variance.

	Num DF	F Val	Pr > F
Aeration	2	0.4	0.6752
Seed Depth	2	14.24	<.0001
Time	5	99.89	<.0001
Aeration x Depth	4	0.66	0.6249
Aeration x Time	10	0.32	0.9752
Depth x Time	10	9.08	<.0001

Hypothesis 2

Unlike the germination test, aeration had a greater effect on plant growth. In addition, sedimentation positively affected stem height. On average, plants receiving 3 cm³ of sediment each week grew faster than 10 cm/week in height while plants receiving 1 cm³ of fresh sediment grew less than 8 cm/week. (See Figure 8 and Table 6.) The results are consistent with previous field studies that determined that annual silt "flushes" in riverine wild rice beds positively affects growth by providing fresh nutrients throughout the year (Meeker 1993).

Standard Deviations

1 cc	2 cc	3cc
2.016597795	2.120198	1.486447

Table 6. Growth Analysis of Variance.

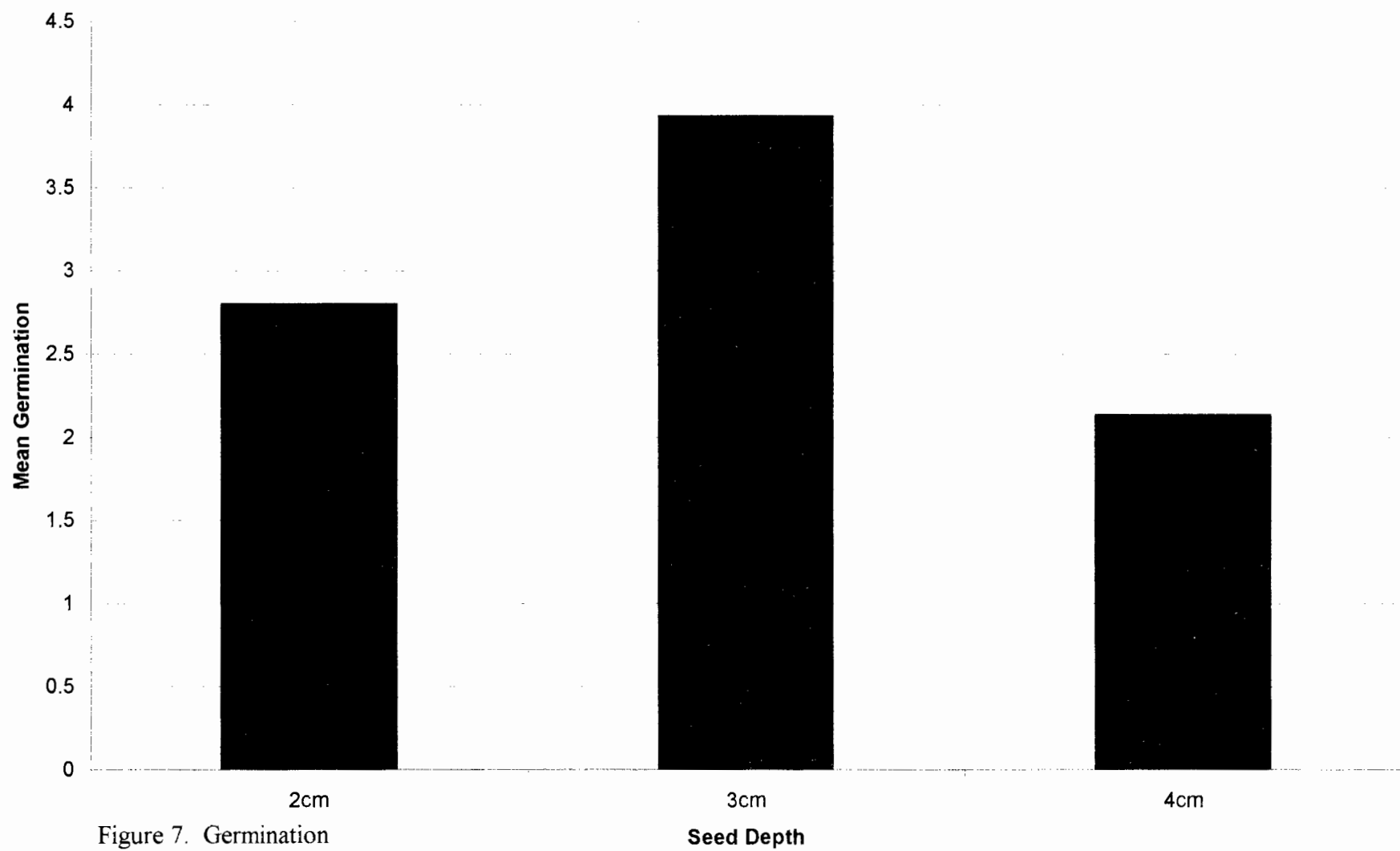
	Num DF	F Val	Pr > F
Aeration	2	5.58	0.0077
Sedimentation	2	5.63	0.0074
Time	3	499.71	<.0001
Aeration x Sediment.	4	1.06	3.891
Aeration x Time	6	2.03	0.0673
Sedimentation x Time	6	2.75	0.0155

DISCUSSION

Due to algal growth along the inside of the buckets of the controlled experiments, dissolved oxygen levels were difficult to maintain. Although I maintained aeration at three levels, average dissolved oxygen for each level was 8.2, 9.1, and 9.6 mg/l respectively. The experiment is not an accurate test of germination responding to varying levels of dissolved oxygen.

The experiment, however, supports previous claims that there is an optimum level of sediment accumulation for wild rice germination (Meeker 1993). The two controlled experiments suggest moderate siltation is not a large threat to overall wild rice health. Instead, the experiments reinforce the notion that wild rice performance is closely linked to a replenishing of nutrients in the substrate.

At Allequash Lake, boat traffic appears to act somewhat like a lawnmower, cutting and slicing the emergent grasses. The wild rice beds in the heavily boated areas are sparse, and the plants are short with skinny stems and relatively large root structures. Whether this is an isolated phenomenon or a regional one is unclear. While turbidity and sedimentation may also increase due to boat traffic at Allequash Lake, my experiments suggest the effects are minor if not moderated by an increase in sedimentation.



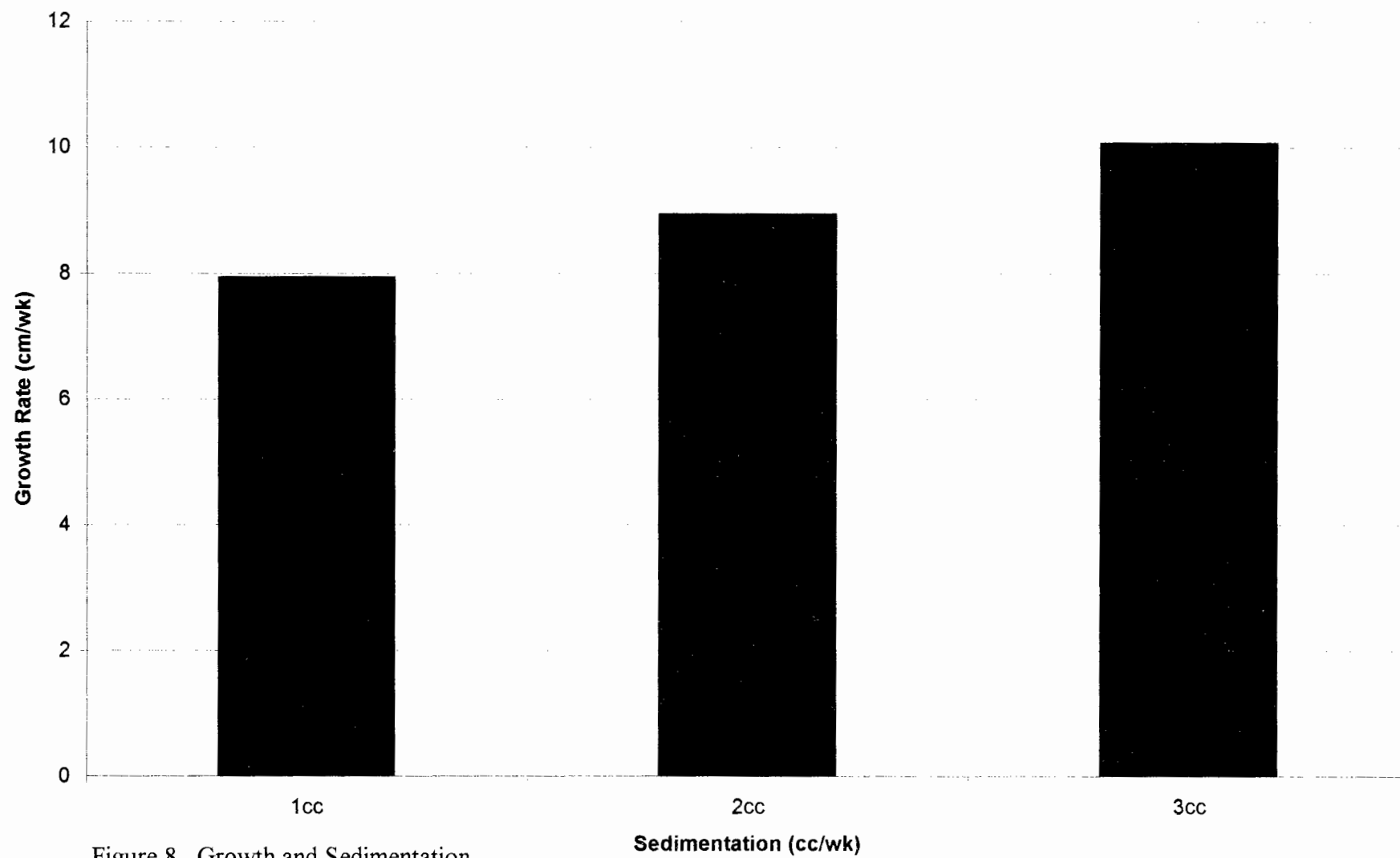


Figure 8. Growth and Sedimentation

The root-mass trends observed at Allequash Lake mimic those of grasses that are frequently cut or grazed throughout their life span (Hofstede and Rossenaar 1995). Given the amount of broken, uprooted, or otherwise damaged plants in the motorized areas, a relatively large root zone is evidence of the plants' efforts to repair or anchor themselves throughout the season. It also explains the "spindly" nature of the plants because new growth is likely to be thinner and less robust than original growth.

Around the world, researchers are studying the effects of motorized boat traffic on freshwater systems. Boat traffic has been linked to increased turbidity, erosion, and an increase in exotic species. As boaters continue to recreate in wild, secluded waters, this research will play a larger role in the management and protection of our freshwater systems.

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THE EFFECTS OF ROOT MASS AND DISTURBANCE ON WILD RICE (*ZIZANIA AQUATICA*) SURVIVORSHIP

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ABSTRACT

Wild rice plants (*Zizania aquatica*) growing in soft, wetland sediments are often uprooted by high winds. A series of surveys and tests are presented in this paper on factors that may be important in the uprooting of wild rice. Naturally occurring wild rice stands in northern Wisconsin were surveyed for morphological characteristics, sediment type, the force needed to uproot rice, and water depth. The force needed to uproot individual plants was positively correlated with root mass but varied considerably with sediment type. In an associated experiment, wild rice seedlings were grown in situ on racks at the edge of a natural rice stand in Rice Lake (Forest Co., Wis.). After 4 weeks, one rack was raised 4 cm and another rack was lowered 4 cm to simulate changes in water level. A third rack was held constant as a control. At the end of 8 weeks, all plants were removed and measured. The changes in water level (both higher and lower) significantly increased the rate plants could be uprooted. Other experiments have shown that sub-lethal concentrations of heavy metals (especially Cu and Zn) resulted in reductions in root mass. Thus, increased metals in the environment could lead to greater incidents of uprooted *Z. aquatica* due to storms or changes in water levels.

INTRODUCTION

Wild rice (*Zizania sp*) can dominate the pristine wetlands of Wisconsin. Despite the plant's cultural, economic, and recreational value, there are still large gaps in our understanding of its ecology. Many areas that historically have had lush wild rice beds no longer support them. Often, the reason for the disappearance of wild rice is not known. It is normal for wild rice beds to occasionally fail (Vennum 1988) due to flooding, wind damage, or unknown

reasons. Pillsbury (unpublished data) found that 15% of the Rice Lake (Forest Co.) rice beds were flattened by wind before they could be harvested.

This study was conducted to address the concerns about the long-term viability of the rice beds of Rice Lake (Forest Co.). It is an important resource for the Sokaogon Chippewa community. These rice stands may be threatened by the development of a zinc and copper mining facility a few miles upstream. Recent research (Lee 1996; Castle and Nimmo, this volume) suggests that increased metals in the environment may have an adverse effect on root growth. These sub-lethal effects may negatively impact wild rice harvests.

Our objectives were to determine the sensitivity of wild rice to small changes of water depth that may occur with the proposed mining operations and to determine the relationship between root development and plant stability.

MATERIALS AND METHODS

Survey

Rice stands from 11 different lakes were used in this study. (See Table 1.) These lakes were chosen for their accessibility and local reputation as good "rice lakes." During the floating leaf stage (June 11-23), ten *Z. aquatica* plants were sampled at random along transects in each of these lakes. A clamp was attached to each of the plants as near to its base as possible. The clamp was then attached to a spring scale to which increasing force was applied until the plant was gently uprooted. Spring scales of different weight ranges were tested on each plant to ensure that the readings always came from the mid-range of the scale, producing more accurate readings. The force needed to uproot these plants was recorded for

Table 1. Sites and dates used in the wild rice survey.

Site	First Sample Date	Second Sample Date
Wabikon Lake (Forest Co.)	6/11/97	7/15/97
Rat River Flowage (Forest Co.)	6/11/97	7/17/97
Rice Lake (Oneida Co.)(Hwy 45)	6/18/97	7/18/97
Big Lake Flowage (Oneida Co.)	6/18/97	7/18/97
Spur Lake (Oneida Co.)	6/18/97	7/18/97
Rice Lake (Vilas Co.)(G)	6/19/97	7/18/97
Irving Lake (Vilas Co.)	6/19/97	7/22/97
Aurora Lake (Vilas Co.)	6/19/97	7/22/97
Allequash Lake (Vilas Co.)	6/19/97	7/22/97
West Plum Lake (Vilas Co.)	6/19/97	7/22/97
Rice Lake (Forest Co.)	6/23/97	7/22/97

each plant sampled. This "force to uproot" was then used as an index of stability. Also measured for each plant was the water depth and dry root and dry shoot mass. The root and shoot for each plant were dried at 105°C for 48 hours (American Public Health Association 1995) and then weighed. These rice stands were surveyed again in July (see Table 1) after their leaves had emerged from the water and similar measurements were taken.

During the second survey, 5 sediment samples were taken at each of the surveyed rice stands using an Ekman grab sampler. Contents were emptied into a bucket and excess water was drained off. A subsample of the sediment was placed into a small plastic bag, sealed, labeled, and stored in a cooler. To determine the bulk density (g dry weight/L of sediment) of the sediment, 30 ml aliquots were taken from each of the above subsamples and dried at 105°C for 48 hours. Percent organic material was determined by weighing dried aliquots and weighing them again after heating to 550°C for 6 hours.

Water Level Manipulations

In the spring of 1997, three adjustable racks were placed in Rice Lake (Forest Co.). In each rack, 15 plastic pots (15 cm deep and 12 cm across) were secured with galvanized steel wire. Using an Ekman dredge, sediment from Rice Lake (Forest Co.) was

collected and placed into each pot to within 2 cm of the rim. All pots were submerged to a depth of 22.5 cm. On June 9 1997, five *Zizania aquatica* seeds were placed 1 cm below the sediment surface of each pot. These seeds had been harvested the previous fall from Rice Lake and were kept viable over the winter by storing them in a burlap sack placed on the bottom of Swamp Creek, the major tributary to Rice Lake (Forest Co.).

Four weeks after the seeds were sown, the racks were inspected and the number of seedlings in each pot was recorded. One rack was chosen randomly to be raised to a depth of 17.5 cm while another rack was randomly chosen to be lowered to a depth of 32.5 cm. The remaining rack was lowered 4 cm and immediately brought back to its former depth so that all seedlings had an equal amount of handling disturbance.

After 8 weeks of plant growth, all remaining wild rice plants were recorded and harvested. The roots and shoots of each plant were separated and plants placed in a drying oven for 48 hours at 105°C and then weighed.

RESULTS

Survey

Figure 1 illustrates the relationship between the bulk density and percent organic carbon of the sediment within the eleven rice stands. As organic matter increases, the bulk density of the sediment decreases. The two rice stands with the highest bulk densities, Irving Lake and Rice Lake (Oneida Co.), were mainly composed of sand and had the smallest percent organic matter.

There is a strong linear correlation (see Figure 2) between root and shoot dry weights in both the floating leaf ($p < 0.001$, $r^2 = 0.75$) and emergent leaf stages ($p < 0.001$, $r^2 = 0.80$). This relationship is not significantly different between sediment types.

Figure 3 shows a significant ($p < 0.05$) but weak negative correlation between water depth and root mass of wild rice plants for both the June and July survey. The two rice stands with mainly sand substrates (Irving Lake and Rice Lake, Oneida Co.) never developed large root masses regardless of the water depth. (See Figure 3.) Figure 4 shows the same pattern with shoot mass and depth. In the July sampling, leaf number was greatest for plants in approximately 38 cm of water and decreased at a greater depths. (See Figure 5.)

In flocculent sediment, wild rice plants with larger root masses were more resistant to uprooting than those with small root masses. (See Figure 6.) This was significant ($p < 0.005$) for both the floating leaf (June survey) and emergent stages (July survey). During the June survey, wild rice found in sandy substrate required greater force to uproot than rice plants grown in flocculent sediment. (See Figure 6.) By July, no relationship could be determined between root mass and the force needed to uproot in wild rice from sandy substrates. (See Figure 6.)

Water Level Manipulations

Between week 4 and 8, decreased water levels resulted in significantly lower ($p = 0.05$) seedling

survival (42%) than the control (77%). (See Table 2.) Lower survivorship was also observed in the high water treatment (63%) but the difference was not significant. In the control treatments, all the plants that did not survive had disappeared (i.e., there were no plants dead yet remaining in the pots). Therefore, it is likely these missing plants had been uprooted. The rice plants exposed to slightly deeper depths had a similar number of missing plants (30%) and 7% were dead and still planted in the pots. Of the rice plants exposed to slightly shallower depths, 35% were completely missing and 23% were dead but still potted.

DISCUSSION

Wild rice in sand substrates showed a lower than average growth in both root and shoot mass (see Figures 3 and 4) and total number of leaves (see Figure 5). This agrees with Keenan and Lee (1988), Lee (1986), and Lee and Stewart (1983) who also found *Z. aquatica* is less robust in sediment with low organic matter. The two lakes in our survey (Irving Lake and Rice Lake, Oneida Co.) that were classified as having sand substrates also had the lowest organic content.

Our data suggest that small, rapid changes in water levels may have a negative impact on wild rice survivorship. Increased water levels when the plant has floating or emergent leaves can increase the upward pull on the roots, which can cause the plant to be uprooted. Kahl (1993) found the floating leaf stage of *Zizania aquatica* to be very sensitive to flooding. Decreased water levels can make these plants "top-heavy" and, thus, more susceptible to wind damage. More gradual changes in water levels may give the plants time to adjust their root-shoot ratios to prevent negative impacts during these sensitive stages.

The optimal water depth for wild rice (judging by root or shoot mass) was 38 cm. Both root and shoot masses, as well as the total number of leaves, decreased in deeper waters. (See Figures 3, 4, and 5.) Stevenson and Lee (1987) also found decreasing root and shoot weights of *Z. aquatica* at increasing

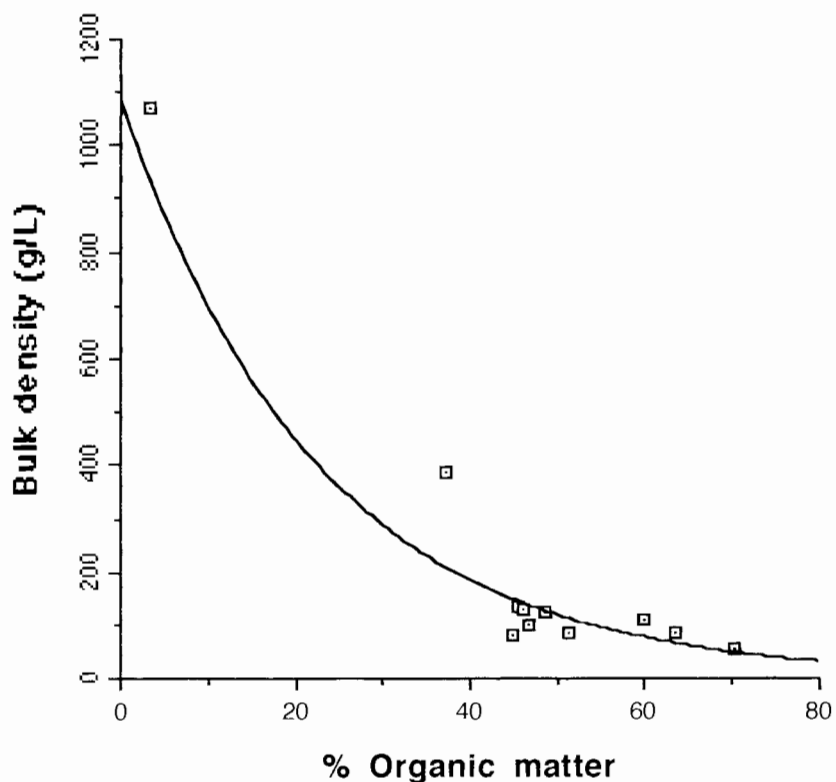


Figure 1. The average % organic matter for the sediments of the surveyed rice stands is plotted against the average Bulk density.

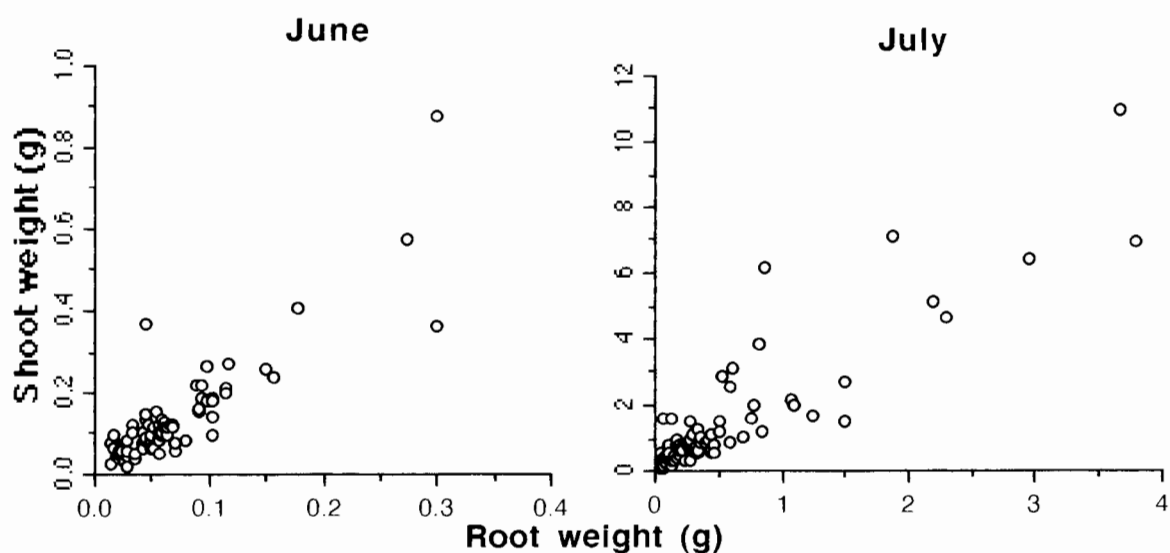


Figure 2. Root weight is plotted against shoot weight of individual wild rice plants from 11 surveyed lakes for both June and July.

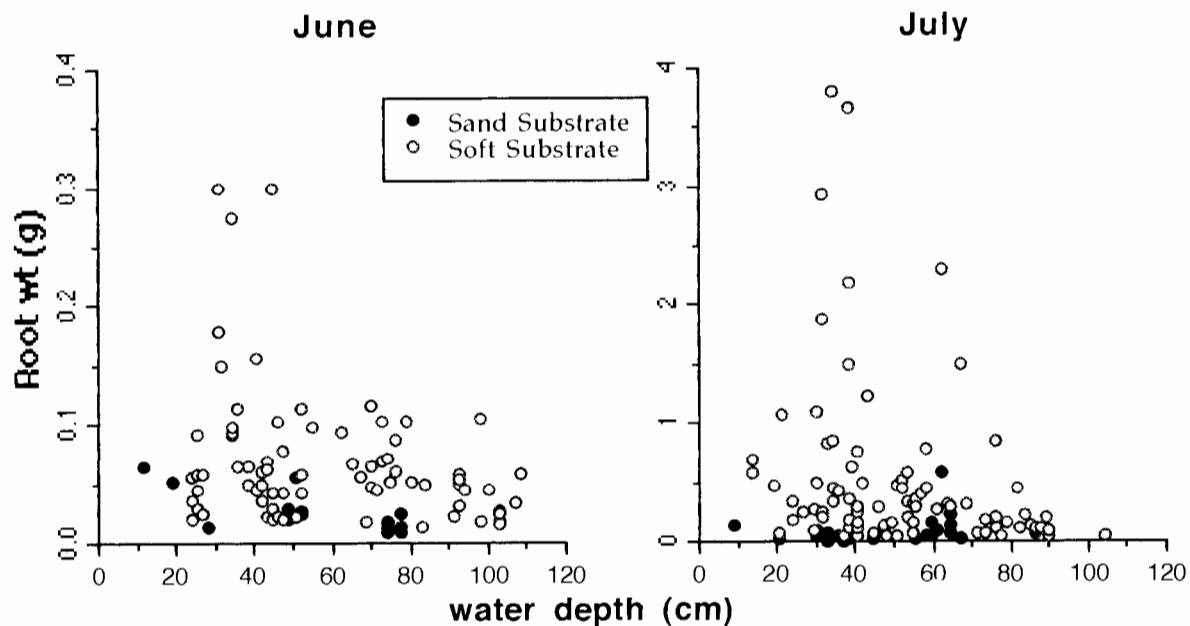


Figure 3. Water depth is plotted against Root weight for individual wild rice plants from 11 surveyed lakes for both June and July. The black circles represent rice sampled from sandy sediment and the white circles represent rice sampled from highly organic sediment.

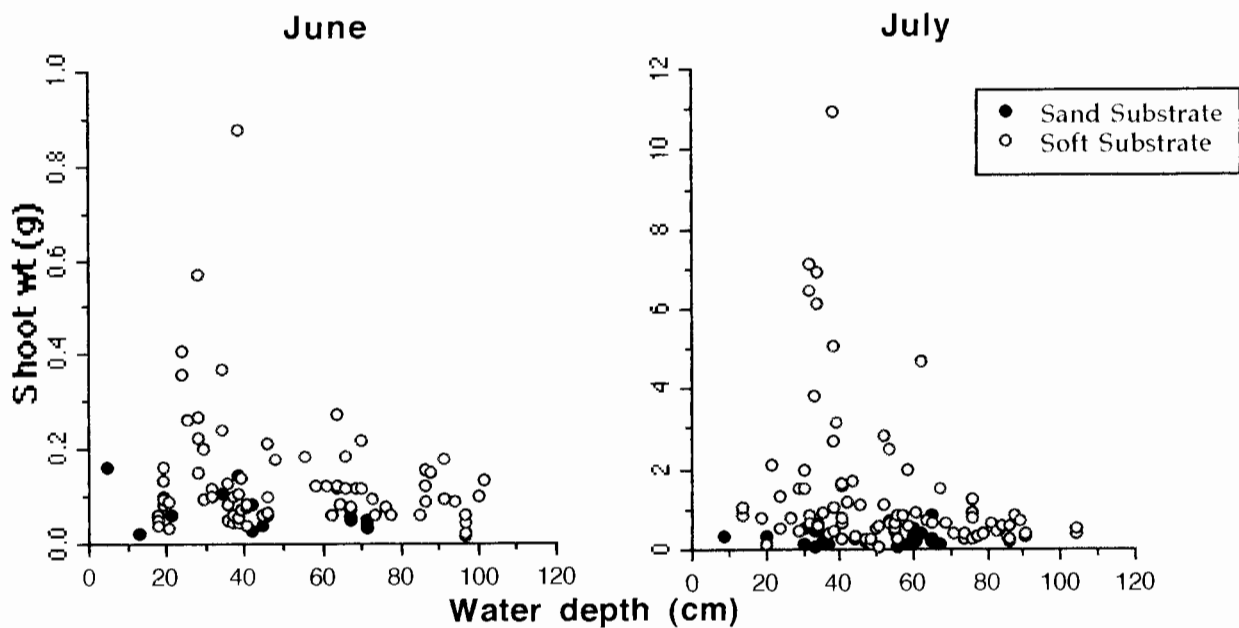


Figure 4. Water depth is plotted against Shoot weight for individual wild rice plants from 11 surveyed lakes for both June and July. The black circles represent rice sampled from sandy sediment and the white circles represent rice sampled from highly organic sediment.

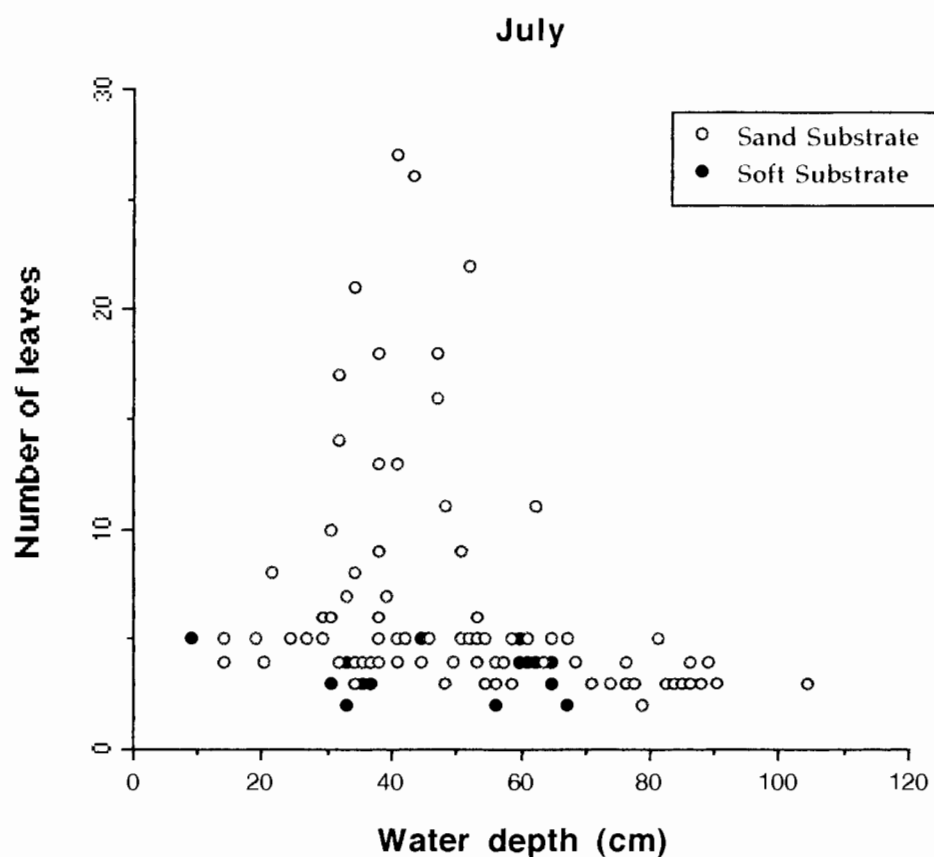


Figure 5. Water depth is plotted against the number of leaves for individual wild rice plants from 11 surveyed lakes for both June and July. The black circles represent rice sampled from sandy sediment and the white circles represent rice sampled from highly organic sediment.

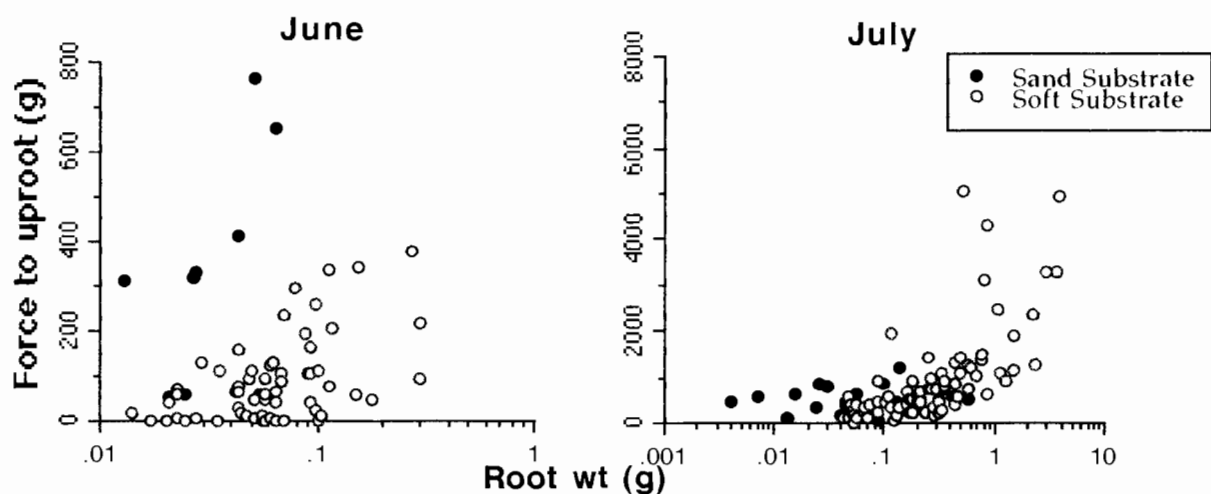


Figure 6. Root depth is plotted the force need to uproot individual wild rice plants from 11 surveyed lakes for July. The black circles represent rice sampled from sandy sediment and the white circles represent rice sampled from highly organic sediment.

Table 2. Wild rice survivorship results given for the control (22.5 cm), high-water treatment (32.5 cm), and low-water treatment (17.5 cm).

Treatment	No. of Plants after 3 Weeks	No. of Plants after 6 Weeks	Survival (%)
Control	36	28	77
High Water	30	19	63
Low Water	26	11	42

water depths with changes as small as 15 cm. In addition, they reported suppressed reproductive output (Stevenson and Lee 1987). Thomas and Stewart (1969) found that *Z. aquatica* grew slower in deeper water where it generally took a longer time between the first appearance of floating leaves and the first appearance of aerial leaves. This is likely caused by a longer path to the surface, less available light, and cooler temperatures at greater depth.

Wild rice plants with larger root masses are more resistant to uprooting in flocculent sediment common to wild rice habitat. (See Figure 6.) Wild rice rooted in sand was harder to pull out compared to plants in flocculent sediment with similar root mass during the floating leaf stage (June). By July, no relationship could be seen between root weights and the force used to uproot (see Figure 6) in sand substrates. It is possible that a significant part of the root mass may have broken off in the sand, although care was taken to collect all roots from these plants. Alternatively, wild rice roots may push through sand at a slower rate than softer sediment. This was suggested by Day and Lee (1988) for wild rice in firm clay sediment as a factor contributing to reduced plant growth.

Wild rice root growth can be further limited by exposure to elevated concentrations of heavy metals. Nriagu and Lin (1995) noted that wild rice was very good at concentrating metals, especially Fe, Cu, and Zn. This has caused some concern about the viability of wild rice beds in areas with elevated aerial deposition (Nriagu and Davidson 1986) and mining activities near important wild rice beds. When Dale and Miller (1978) re-surveyed 23 sites around Sudbury, Canada, after the establishment of

the copper/nickel smelter, once-existing wild rice stands had disappeared. Rivers with increased metal concentrations (Ca, Cu, and Pb) downstream of hydroelectric developments show a decrease in macrophyte species richness. Root mass of *Z. aquatica* is also reduced in acidic conditions (Borland and Burk 1992), which is another condition in which metals are more likely to be motile (Jackson et al. 1993b). Increased acidity and metals from aerial deposition were the suspected causal agents. Painchaud and Archibold (1990) found poor wild rice (*Zizania palustris*) growth in sediments below -200 Eh where many of these metals would be mobilized. This problem is potentially worsened because once metals are mobilized, they tend to concentrate in areas otherwise suitable for wild rice (Chen 1992). Pip (1993) and Jackson and others (1993a) found that levels of Cu in wild rice seeds correlated with Cu levels in the sediment although Lee and Stewart (1983) found an inverse correlation. Lee (1996) exposed rice seedlings in growth media to various heavy metals (Al, Cd, Cu, Pb, and Hg). All of these metals affected the seedlings by reducing root and shoot mass. Castle and Nimmo (this volume) determined that at sub-lethal levels of Cu, early root development was reduced. Significant reduction in root mass was seen after only 14 days at 200ug Cu/L.

It is possible that increased concentrations of heavy metals may indirectly cause increases in the uprooting rates due to storms or water fluctuations. This can occur by reducing the root mass of the plants, which makes them more susceptible to uprooting. This, in turn, can increase the failure rate of rice harvests over the long term. Caution should

be applied to insure that long-term management of important wild rice beds is compatible with other watershed activities such as mining. To insure long-term viability of these rice beds, sub-lethal effects should be taken into account. The proposed mine is likely to impact Rice Lake (Forest Co.) by potentially changing flow patterns, water depth, and metal concentrations. Given the known sensitivities of wild rice, the current lack of knowledge concerning wild rice ecology (especially long-term management), and the unforeseen consequences of large mining operations on a watershed over the next century, further research and a conservative approach are called for.

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POSTER/ORAL PRESENTATION

EFFECTS OF COPPER METAL ON *ZIZANIA AQUATICA*, WILD RICE SEEDLINGS, FROM MOLE LAKE, WISCONSIN

C. J. Castle
D. R. Nimmo

ABSTRACT

The sensitivity of wild rice and aquatic organisms to metals was investigated. Waters from Swamp Creek were fortified (spiked) with metals to quantify their toxic effects on wild rice and aquatic organisms in their natural media. Baseline tests were conducted to determine if Swamp Creek water was toxic to test organisms. Tests using invertebrates and fish were conducted in spring and fall of 1996. No baseline toxicity was detected. The second phase of research in the fall of 1996, spring of 1997, and spring of 1998 included tests on natural waters fortified (spiked) with metals to determine differences in the sensitivity of resident or surrogate aquatic species to additional metals. The results of metal-spiked tests raise questions about the sensitivity of key species to an increase in levels of bioavailable metals.

INTRODUCTION

The Mole Lake Indian Reservation lies approximately six miles southwest of the town of Crandon in Forest County, Wisconsin. The Reservation was established to protect a primary cultural resource of the Mole Lake Band of the Sokaogon Chippewa, the naturally occurring wild rice, *Zizania aquatica*, of Rice Lake. This study is in the "Site Characterization" phase, as we consider how metals affect wild rice growth.

METHODS

Methods for conducting the baseline studies and tests in which metals were added to natural or artificial waters are listed in the References section of this paper. Also listed are key publications that we reviewed prior to initiating the studies.

Between June 17 and 29, 1996, baseline toxicity tests with daphnids, fish, amphipods, and barnyard grass seedlings were conducted on site water and sediments in the Swamp Creek and Rice Lake drainage. The purpose of the tests was to determine if water or sediments from the creek were toxic (i.e., that a specific contaminant or combination of contaminants was detectable at toxic level by conducting toxicity tests with aquatic species). Species tested were larval fathead minnows, *Pimephales promelas*; a daphid, *Ceriodaphnia dubia*; an amphipod, *Hyalella azteca*; and a grass often found in wetlands, *Echinochloa crusgalli*. All these species have been found in Rice Lake with the exception of *E. crusgalli*, the barnyard grass.

Samples of Swamp Creek water collected as grab samples were tested with daphnids and minnows. Pore waters, derived by centrifuging wet sediments, were tested with amphipods and barnyard grass seeds. The sites sampled were: two along Swamp Creek; one in Rice Lake; and one in Gliske Creek, a tributary that enters Rice Lake from the north.

The objective of the metal spike tests was to compare the sensitivities of organisms in natural waters from the various basins in the vicinity of the proposed mine. Test organisms chosen for the studies included daphnids, *Ceriodaphnia dubia*; larval fathead minnows, *Pimephales promelas*; and walleye, *Stizostedion vitreum vitreum*. As a control reference, tests were also conducted in artificial laboratory water (RECON=artificial or reconstituted laboratory water).

Wild rice, *Zizania aquatica*, seed germination was also tested with copper added to Swamp Creek water. Cold ripened wild rice seed was obtained

from Rice Lake, Forest County, Wisconsin, for these tests. In this study, the average weight gains of germinating seeds were plotted against copper concentrations.

RESULTS OF BASELINE STUDIES CONDUCTED IN THE SPRING, 1996

The principal conclusion from the June 1996 study was that there was no evidence that waters from the sites were currently toxic to invertebrates, fish, or barnyard grass. The number of amphipods surviving more than seven days in pore water exceeded 97.0%. The number of fathead minnows surviving in site waters in the chronic tests (seven days) exceeded 87.0%. The number of surviving daphnids was 100 percent (eight-day chronic exposure). The number of young born to female daphnids (within eight days) exposed to Swamp Creek and Gliske Creek waters were double the number produced in reconstituted laboratory water, indicating that both watersheds appear to be of excellent quality. There was no evidence that any of the pore waters were toxic to barnyard grass (*Echinochloa crusgalli*) using percent germination in three days as an endpoint.

RESULTS OF BASELINE STUDIES CONDUCTED IN THE FALL, 1996

During October 1996, baseline toxicity tests with daphnids, fish, amphipods, and barnyard seedlings were conducted on site waters and sediments in the Swamp Creek drainage. Because we found no evidence of toxicity in the spring studies, we reduced the number of sampling sites to two on Swamp Creek and one on Gliske Creek. As in the spring studies, the purpose of the tests was to determine if water or sediments from the creek were toxic (i.e., that a specific contaminant or combinations of contaminants were detectable in waters or sediments by testing with aquatic species).

Again, there was no evidence that toxic conditions existed at any of the sites. Survival of amphipods in the fall was less than in the spring at one of the sites on Swamp Creek but survival at the other sites was

similar to the spring survival. Survival of fathead minnows was lower in the fall but not significantly different from spring survival. Survival and reproduction of daphnids were similar to spring results. Germination of barnyard grass was similar to spring results.

RESULTS OF NATURAL WATERS SPIKED WITH METALS, 1996

Results of copper added to natural and artificial waters showed copper to be toxic to the daphnids at parts-per-billion concentrations. Copper was toxic to the daphnids in both soft and moderately hard reconstituted (artificial) waters with LC50 (lethal concentration for 50 percent of the organisms) values less than 5.0 ug/l. The LC50 value for copper in Swamp Creek water was 14 ug/l. This value is compared to an LC50 of 52 ug/l copper in water from the Duck Lake Drainage. These differences in toxicity values in adjacent drainages suggest that Swamp Creek water is different in its geochemistry and should be considered separately when assessing potential impacts of human activities on water resources in the area.

With the natural and artificial waters spiked with lead, we found this metal to be acutely toxic to the daphnids. The LC50 value in soft reconstituted water was <5 ug/l. Whereas, in moderately hard water, the LC50 was 343 ug/l, which demonstrates the detoxifying influence of calcium or magnesium and carbonates in the mineral salts used in the hard artificial water. In the natural waters, the LC50 was 279 ug/l in Swamp Creek but in Duck Lake drainage water, only 20% of the daphnids died in a nominal concentration of 800 ug/l of lead, and, therefore, an LC50 could not be determined. As observed in the tests with copper, differences in LC50s between these waters suggests that Swamp Creek water has different geochemistry resulting in greater toxicity of metals compared to the Duck Lake watershed.

In successive tests using daphnids and fathead minnows in which copper was added to Swamp Creek and Gliske Creek waters, we found the LC50s

Table 1. Copper effects on wild rice seedling growth.

Wild Rice Copper Spike Tests May 1997		
Copper (ug/l)	Average Wt (g)	Results of Statistical Analyses
0	0.2562	Inhibition Concentration 25 (IC25) = 195.6 ug/l Cu
100	0.2427	Dunnett's No Observed Effect Conc. (NOEC) = 100 ug/l Cu
200	0.1892	Bonferroni T-Test (NOEC) = 100 ug/l Cu
400	0.1464	Steel's Many One Rank Test (NOEC) = 100 ug/l Cu
1650	0.0890	NOECs also correlate with root growth (effect at 200 ug/l).

for daphnids to be the same (i.e., LC50s were 40 ug/l and 42 ug/l, respectively). An LC50 for daphnids in moderately hard reconstituted water was 3.5 ug/l, similar to the <5 ug/l values reported above in the October tests. Larval fathead minnows were not as sensitive to the copper in natural waters, with an LC50 of 337 ug/l in Swamp Creek water and an LC50 of 458 ug/l in Gliske Creek water. However, for the fish, the LC50 value was lower in Swamp Creek water than in Gliske Creek water, again suggesting that the characteristics of Swamp Creek water may differ geochemically and be less protective to fish from the toxicity of copper.

RESULTS OF NATURAL WATERS SPIKED WITH COPPER, 1997

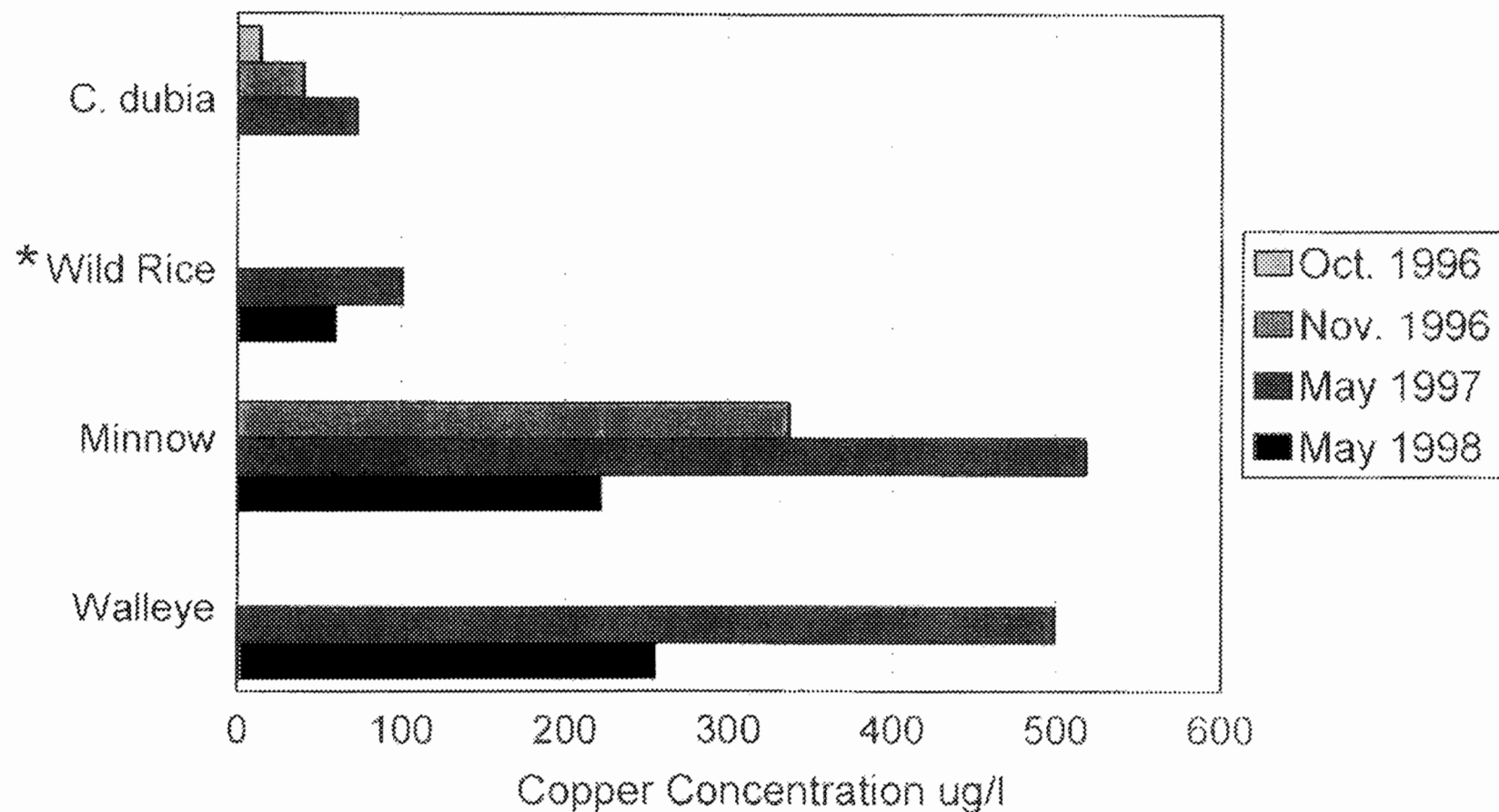
In May 1997, survival tests on walleye (*Stizostedion vitreum vitreum*), fathead minnows, and daphnids were conducted with site waters (Swamp and Gliske creeks) in which copper was added as a test metal at nominal concentrations. The data confirm earlier findings that Swamp Creek has less calcium, magnesium, and carbonates than Gliske Creek, and, therefore, is less protective of fish.

Copper was as acutely toxic to larval walleye as it was to larval fathead minnows but differences between these species depended on the source of the test water. For the walleye, an LC50 of 182 ug/l was

found in moderately hard reconstituted water; an LC50 of 496 ug/l was found in Swamp Creek water; and an LC50 of 683 ug/l was calculated in Gliske Creek water. Similar results were found with larval fathead minnows, however, the walleye were slightly more sensitive.

The effects of copper on daphnids using the no observed effect concentration (NOEC) as opposed to lethal concentrations (LC50s) again showed no differences between Swamp Creek and Gliske Creek water based on survival. However, using the endpoint of reproduction, or the average number of young per female, the NOECs were significantly lower. Also, the NOECs for daphnid reproduction in copper-spiked Swamp Creek water (10 ug/l) was significantly lower than in Gliske Creek water spiked with copper (40 ug/l).

Wild rice seed growth was significantly affected by copper spiking of Swamp Creek water between 100 and 200 ug/l of added copper. (See Table 1.) For example, the 25% growth inhibition concentration (IC25) was 196 ug/l copper based on Bootstrap/Linear Interpolation estimates. The no-observed-effect concentration (NOEC) was 100 ug/l using Dunnett's Test, Bonferroni's T-Test, and Steel's Many One Rank Test. We also found that the NOECs appeared to correlate with root growth (i.e., morphological effects including root abscission was evident at 200 ug/l). We found that the



* NOEC = No Observed Effect Concentration

Figure 1. Swamp Creek Copper Spike LC50s

concentration of copper that affects growth of wild rice was lower than the LC50 concentrations for fathead minnows in previous tests.

Wild rice seed germination tests appear to be sensitive indicators of the effects of copper, showing lower threshold effects than larval fathead minnows. (See Figure 1.) In Swamp Creek water, the no-effect-concentration (NOEC) for wild rice was 60 to 100 ug/l of copper. The IC25 for wild rice was 196 ug/l compared to a LC50 for fathead minnows of 200 to 500 ug/l of copper.

DISCUSSION

Baseline toxicity tests did not indicate the presence of toxic levels of bioavailable contaminants in surface and interstitial waters in Swamp Creek or Rice Lake. Testing with metals-fortified (spiked) surface water was conducted to establish the threshold of metals toxicity to aquatic life in Swamp Creek. Acute toxicity tests with spiked waters suggest that small increases in bioavailable metals in Swamp Creek may have a substantial adverse effect on invertebrates and/or wild rice.

Copper affects wild rice at the root of the plant. In addition to the measured effects on wild rice sprout weight, visual observation in exposures found a reduction in root growth and root "cork screwing" in the presence of copper. A reduction in the root length and cork screwing may hamper plant anchoring in sediment.

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